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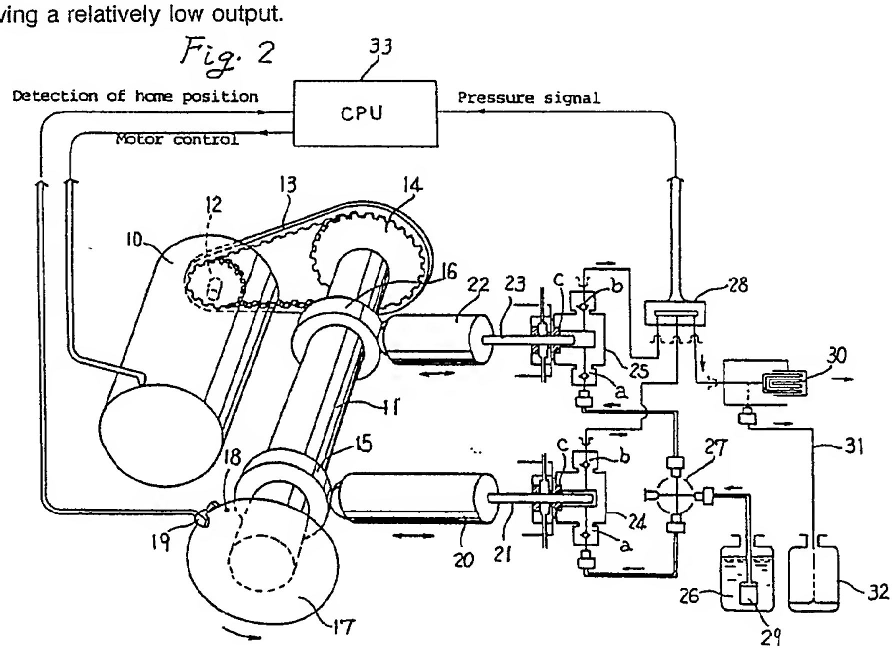
(54) **Reciprocating type fluid delivery pump.**

(57) A reciprocating type fluid delivery pump has a driving motor (10), plungers (21, 23) for driving two pump heads (24, 25), respectively, and a converting mechanism for converting the rotational motion of the driving motor into a reciprocating motion of each plunger (21, 23). The converting mechanism includes a cam (15, 16) having such a configuration that, when the driving motor (10) is rotated at constant velocity, the delivery flow rate during the delivery starting period of each of the plungers (21, 23) is in excess of that during the other periods of the cycle. The speed of rotation of the driving motor (10) is reduced during the excess delivery period according to need. Thus, the load on the driving motor (10) is reduced and it is therefore possible to employ a driving motor (10) having a relatively low output.

Fig. 2



RECIPROCATING TYPE FLUID DELIVERY PUMP

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a relatively small-volume fluid delivery pump wherein two plungers reciprocate to deliver a fluid, that is, a so-called small-volume plunger reciprocating type fluid delivery pump which may be used, for example, to deliver a mobile phase in liquid chromatography.

2. Description of the Related Art

A typical conventional small-volume plunger reciprocating type fluid delivery pump has a driving motor, plungers for driving two pump heads, respectively, and a converting mechanism for converting the rotational motion of the driving motor into a reciprocating motion of each plunger.

Fig. 4 shows the plunger speed characteristics with respect to an angle θ of a conventional small-volume plunger reciprocating type fluid delivery pump having two pump heads.

The curve 1 shows the plunger speed characteristics of the first pump head, while the curve 2 shows the plunger speed characteristics of the second pump head. A cam is used as a converting mechanism for converting the rotational motion of the driving motor into a reciprocating motion of each plunger. The axis of ordinates, i.e., $dr/d\theta$ (r is the distance from the center of rotation of the cam), represents the plunger speed at the time when the driving motor is rotating at a constant velocity. The upper and lower sides of the axis of abscissas show the plunger speeds at the deliver and suction sides, respectively.

The cam is shaped such that $dr/d\theta$ shows a trapezoidal pattern.

In the case of an ideal fluid whose delivery flow rate is proportional to the delivery-side plunger speed, the flow rate of the fluid being delivered, which is the sum of the respective delivery flow rates of the two pump heads, is constant throughout all angles of the cam when the driving motor is rotated at constant velocity, as shown by the reference numeral 3 in Fig. 4.

In practice, however, it is impossible to deliver a fluid at the beginning of the trapezoidal delivery cycle if the pressure is excessively high due to the compressibility of the fluid, the delay in response of a check valve and other factors, and deficiencies 4 and 5 occur in the delivery flow rate and the pressure as shown in Fig. 5. The result is a periodic pulsing flow which leads to a noise in a detection which must be carried out with a high sensitivity.

In order to reduce pulsations in the delivery of fluids, it is conventional practice to control the speed of rotation of the driving motor such that, during the beginning of delivery where the pressure may be insufficient the motor is rotated faster than in the other periods of the cycle.

More specifically, U.S. Patent No. Re. 31,608, Magnussen, Jr., discloses a fluid pump mechanism for delivering fluid against a back pressure which comprises a piston movable within a chamber for drawing fluid into the chamber during a chamber filling interval, pressurizing the fluid during a pressurizing interval wherein the fluid pressure attains an effective delivery value prior to delivery from the chamber and delivering the pressurized fluid from the chamber during a delivery interval of piston movement, and means for controlling the rate of piston movement such that the piston moves at a predetermined rate during delivery of the pressurized fluid. The controlling means includes a "pump-up" means for establishing a greater rate of piston movement during the pressurizing of the fluid, for signalling completion of fluid pressurization, and for thereupon establishing the predetermined rate of piston movement for effecting delivery of the pressurized fluid from the chamber, thereby increasing the time during which fluid is delivered to a receiving system and decreasing the time of filling or refilling and pump-up prior to such delivery, and thus enabling fluid to be delivered at a given flow rate and with a greatly reduced pulsation.

U.S. Patent No. 4,045,343, Achener et al., discloses a high pressure liquid chromatography system including a reservoir for a liquid mobile phase, an LC column and detector, a high pressure reciprocating pump for enabling flow from the reservoir through the column, and a positively actuated inlet valve for controlling flow from the reservoir to the pump chamber. The pump is driven by motor means, such as a stepping motor, directly coupled thereto; and the inlet valve is actuated by the power train of the motor and pump, e.g., by an eccentric carried by the pump crank shaft. The pump piston is similarly driven by an

eccentric, the pump and inlet valve eccentrics being angularly displaced in their respective positions at the crank shaft, as to delay opening of the inlet valve for a predetermined period following a pump stroke, in order to enable decompression of the liquid in the pump chamber. The average rotational velocity of the stepping motor is controlled throughout each full crank shaft rotation, so as to enable a precisely selected cycle of pump operation. In particular, the speed of the motor is so regulated in conjunction with the mechanical actuation of the pump piston and inlet valve as to provide (at the low flow rates where such behavior is critical) a very short duration fill period--which implies a rapid withdrawal of the piston or plunger from the pump cylinder. Thereafter, the second portion of the pumping cycle, which corresponds to pumping or displacing the liquid from the pump toward the chromatographic column, is effected under crank shaft rotation (as a function of time) such that the axial displacement of the piston is relatively linear as a function of time.

Fig. 6(A) shows compensation for pulsations in the case where a fluid is delivered under high pressure, while Fig. 6(B) shows pulsation compensation in the case where the delivery of a fluid is effected under low pressure. The reference symbol a represents a pulsing flow in the case where the speed of rotation of the cam is kept constant; b represents the speed of rotation of the cam controlled so as to compensate the pulsing flow; and c represents the pulsing flow thus compensated.

The higher the pressure, the greater the deficiency in pressure; therefore, as the pressure is increased, the rotational speed of the driving motor must be increased correspondingly.

Thus, the prior art method wherein the rotational speed of the driving motor is varied to reduce pulsations suffers from the problem that, as the pressure is increased, the rotational speed of the driving motor must be increased correspondingly to make compensation, and therefore the load on the motor increases and a driving motor having a relatively high output is needed.

SUMMARY OF THE INVENTION

In view of the above-described circumstances, it is a primary object of the present invention to provide a reciprocating type fluid delivery pump which is so designed that it is possible to compensate for pulsations occurring due to the compressibility of a fluid and other factors during the delivery starting period in a state wherein no load is applied to the driving motor.

To this end, the present invention provides a reciprocating type fluid delivery pump having a driving motor, plungers for driving two pump heads, respectively, and a converting mechanism for converting the rotational motion of the driving motor into a reciprocating motion of each plunger, wherein the converting mechanism includes a cam having such a configuration that, when the driving motor is rotated at constant velocity, the delivery flow rate during the delivery starting period of each of the plungers is in excess of that during the other periods of the cycle, and the speed of rotation of the driving motor is reduced during the excess delivery period according to need.

By virtue of the above-described arrangement, in such an ideal state that the flow rate of a fluid being delivered is proportional to the delivery-side speed of a plunger, if the driving motor is rotated at constant velocity, the delivery flow rate during the delivery starting period of the plunger is in excess of that during the other periods of the cycle. In the case where an ordinary fluid is delivered under high pressure, a deficiency in the delivery flow rate occurs during the delivery starting period due to the compressibility of the fluid and other factors. Therefore, the deficiency is cancelled by the excess that is provided on the basis of the configuration of the cam.

In the case where a fluid is delivered under low pressure, if the driving motor is rotated at a constant velocity, the excess in the delivery flow rate that is provided by virtue of the cam configuration remains, so that the fluid is delivered to an excess. Therefore, the rotational speed of the cam is reduced during the excess delivery period so that the delivery flow rate is maintained at a constant level.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become clear from the following description of the preferred embodiment thereof, taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a chart showing the relationship between the plunger speed characteristics and the delivery flow rate at a time when the driving motor is rotated at constant velocity in accordance with one embodiment of the present invention;

Fig. 2 shows the arrangement of one embodiment of the present invention;

Fig. 3(A), 3(B) and 3(C) show the operations of one embodiment of the present invention under different pressures;

Fig. 4 is a chart showing the relationship between the plunger speed characteristics and the delivery flow rate at the time when the driving motor is rotated at a constant velocity in a conventional fluid delivery pump;

Fig. 5 is a chart showing the relationship between the delivery flow rate and pressure in the conventional fluid delivery pump; and

Fig. 6(A) and 6(B) show the operations of the conventional fluid delivery pump under different pressures.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will be described hereinunder in detail with reference to the accompanying drawings.

Fig. 2 shows a small-volume plunger reciprocating type fluid delivery pump to which the present invention is applied.

The reference numeral 10 denotes a driving stepping motor, and 11 a cam shaft. The rotation of the stepping motor 10 is transmitted to the cam shaft 11 through a small pulley 12, a belt 13 and a large pulley 14 which is secured to the cam shaft 11.

The cam shaft 11 has two cams 15 and 16 secured thereto for driving two pump heads, respectively. The cam shaft 11 further has a disk 17 secured thereto. The disk 17 is provided with a bore 18, so that the home position relative to the rotational angle of the cams 15 and 16 is detected by detecting the bore 18 by means of a photocoupler 19.

The proximal end of a crosshead 20 is in contact with the cam 15 so that the crosshead 20 performs a reciprocating motion. A plunger 21 of a first pump head 24 is secured to the other end of the crosshead 20. Similarly, the proximal end of a crosshead 22 is in contact with the other cam 16 so that the crosshead 22 performs a reciprocating motion, and a plunger 23 of a second pump head 25 is secured to the crosshead 22.

Cams 15 and 16, which will be described later in detail, are designed to have configurations that provide angle-plunger speed characteristics as shown in Fig. 1.

At the first pump head 24, the reciprocating motion of the plunger 21 causes a fluid 26 to be delivered to a flow path leading to a pressure sensor 28 from a suction filter 29 and an inlet block 27. At the second pump head 25 also, the reciprocating motion of the plunger 23 causes the fluid 26 to be delivered to a flow path leading to the pressure sensor 28 from the suction filter 29 and the inlet block 27. At each of the pump heads 24 and 25, the reference symbol a denotes an inlet check valve, b an outlet check valve, and c seal member.

In the pressure sensor 28, the fluids respectively delivered from the first and second pump heads 24 and 25 are joined together and are then delivered from a pump outlet 30 to a flow path which leads to a column. Reference numeral 31 denotes a drain flow path, and 32 a drain bin.

The reference numeral 33 denotes a CPU. A pressure signal from the pressure sensor 28 and a home position detecting signal from the photocoupler 19 are sent to CPU 33. CPU 33 controls the speed of rotation of the stepping motor 10.

The configurations of the cams 15 and 16 are determined so that the $dr/d\theta$ (the plunger speed at the time of uniform rotation) characteristics with respect to the cam rotational angle θ are set such as those shown in Fig. 1. In Fig. 1, the curves 1a and 2a represent the $dr/d\theta$ characteristics of the first and second pump heads, respectively.

The following is the cam configuration that provides the $dr/d\theta$ characteristics shown in Fig. 1.

$0<\theta\leqq 10$	$r = 15.5 + 0.075\theta^2/294.14062$
$10<\theta\leqq 25$	$r = 15.5 + (1.5\theta - 7.5)/294.14062$
$25<\theta\leqq 70$	$r = 15.5 + (7\theta^2/180 - 4\theta/9 + 605/36)/294.14062$
$70<\theta\leqq 205$	$r = 15.5 + (5\theta - 173.75)/294.14062$
$205<\theta\leqq 220$	$r = 15.5 + (-8\theta^2/90 + 373\theta/9 - 140735/36)/294.14062$
$220<\theta\leqq 250$	$r = 15.5 + (-7\theta^2/180 + 175\theta/9 - 53615/36)/294.14062$
$250<\theta\leqq 300$	$r = 15.5 + (-0.1255\theta^2 + 62.75\theta - 6902.5)/294.14062$
$300<\theta\leqq 340$	$r = 15.5 + (-12.55\theta + 4392.5)/294.14062$
$340<\theta\leqq 360$	$r = 15.5 + (0.31375\theta^2 - 225.9\theta + 4066.2)/294.14062$

As shown in Fig. 1, if the driving motor is rotated at constant velocity, the sum of the respective speeds of the two plungers is larger during the delivery starting period of each plunger than during the other periods of the cycle. Therefore, assuming that the flow of the fluid accurately follows the delivery-side plunger speed, the delivery flow rate 3a goes to excess during the delivery starting period in each cycle, as shown by the reference symbol A.

Figs. 3(A)-3(C) show the relationship between the pressure and the rotational speed of the driving motor in this embodiment.

Fig. 3(A) shows the pulsation compensation that is made in the case where fluid delivery is carried out under substantially no pressure. If the driving motor is rotated at constant velocity, excesses A occur in the delivery flow rate during the delivery starting period in each cycle, as shown by graph a. Therefore, the driving motor is decelerated such that the rotational speed of each cam is reduced during each delivery starting period, as shown by graph b. As a result, the delivery flow rate becomes constant as shown by graph c.

Fig. 3(B) shows the pulsation compensation that is made in the case where the fluid delivery is carried out under low pressure. If the driving motor is rotated at constant velocity, an excess A′ in the delivery flow rate appears in the temporally latter portion of each excess delivery period, as shown by graph a. Therefore, the rotational speed of the motor is reduced as shown by graph b. As a result, the delivery flow rate becomes constant as shown by graph c.

Fig. 3(C) shows the pulsation compensation made in the case where the fluid delivery is carried out under high pressure. In this case, deficiencies in the delivery flow rate due to high pressure and excesses in the delivery flow rate due to high pressure and excesses in the delivery flow rate due to the modification of the cams cancel each other, so that the delivery flow rate in graph a at the time when the driving motor is rotated at constant velocity is constant. Accordingly, there is no need to compensate the rotational speed in graph b of the driving motor.

Since the relationship between the pressure and the optimal amount of compensation (i.e., the driving motor deceleration period) depends on the kind of fluid delivered, it may be possible to set the relationship in advance or obtain it automatically while monitoring the level of the pressure.

The compensation that is made by decelerating the driving motor is conducted in a relatively low flow rate region where it is highly essential to reduce pulsations. In flow rate regions where the flow rate is high and fluid delivery is effected at high frequency, pulsations are small, so that it is unnecessary to reduce the rotational speed of the driving motor to compensate. In such a case, the cams may be rotated at constant velocity.

In the present invention, the configurations of cams for reciprocating respective plungers are improved so that, when the driving motor is rotated at constant velocity, the delivery flow rate during the delivery starting period of each of the plungers is in excess of that during the other periods of the cycle. Therefore, the speed of rotation of the driving motor is controlled in such a manner that, when the fluid is delivered under low pressure, the rotational speed is reduced, whereas, when the fluid delivery is carried out under high pressure, the motor is rotated at constant velocity. Accordingly, the load on the driving motor is reduced and it is possible to employ a driving motor having a relatively low output in comparison with the conventional compensation wherein the rotational speed of the driving motor is increased under high pressure.

Although the present invention has been described above through specific terms, it should be noted here that the described embodiment is not necessarily exclusive and various changes and modifications may, of course, be imparted thereto without departing from the spirit and scope of the present invention which is limited solely by the appended claim.

Claims

1. A reciprocating type fluid delivery pump with two pump heads, comprising:
a driving motor;
a pair of plungers for driving said two pump heads, respectively;
a converting means for converting the rotational motion of said driving motor into reciprocating motion of each plunger, wherein said converting means includes, a cam means, engageable with said plungers, for reciprocating said plungers to provide a delivery flow rate of fluid from each plunger which is in excess of that during other periods of each plunger cycle, when said driving motor is rotated at a constant velocity; and
a means for selectively decelerating said driving motor said driving motor driving said excess delivery period when fluid delivery is not carried out under high pressure.

2. The pump of claim 1, wherein said cam means includes a pair of cams, each cam engaging a corresponding one of said plungers.

3. The pump of claim 1, wherein said decelerating means decelerates said driving motor during said excess delivery period when said fluid delivery is carried out under low pressure.

Fig. 1

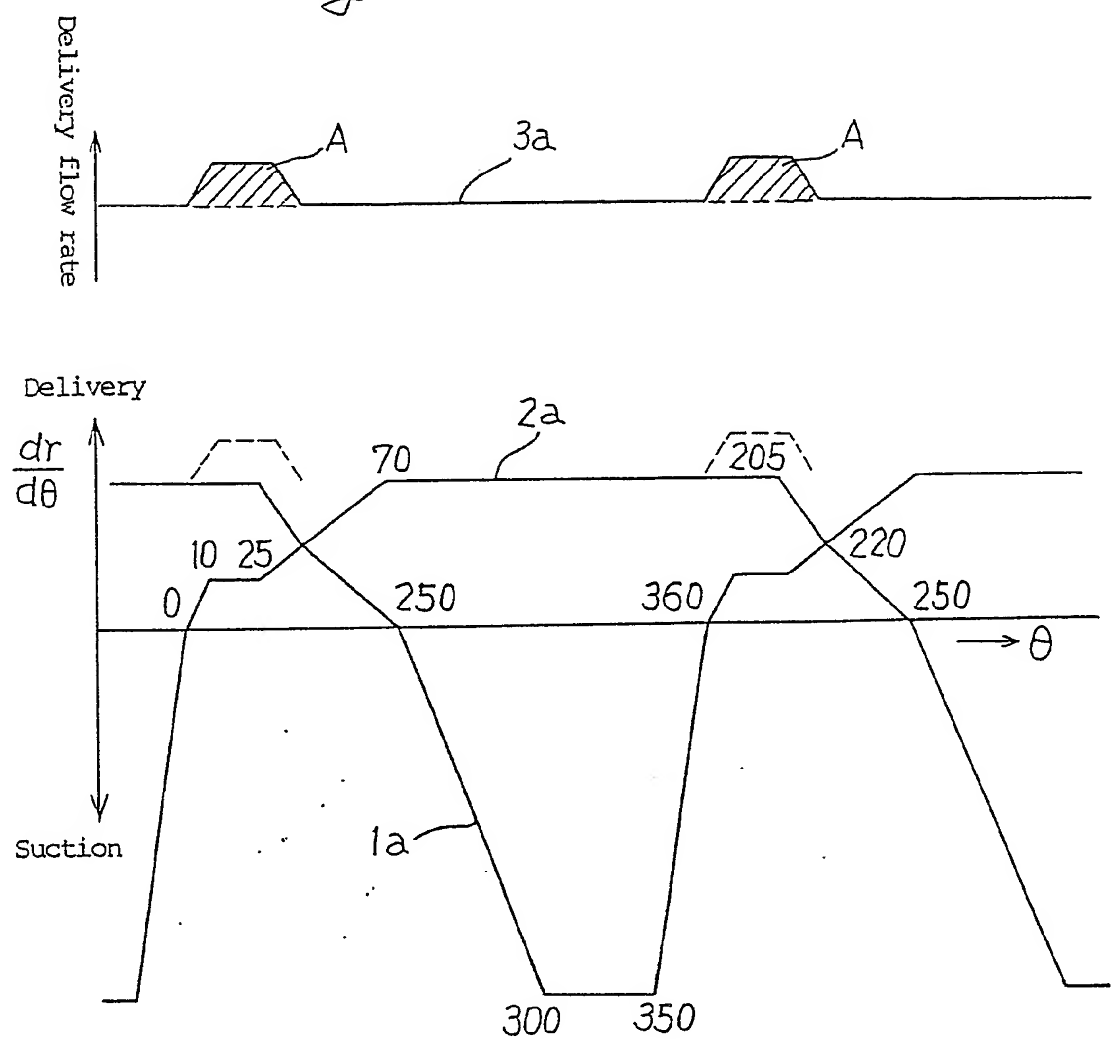


Fig. 3 (A)

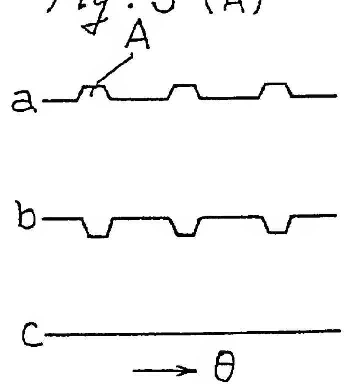


Fig. 3 (B)

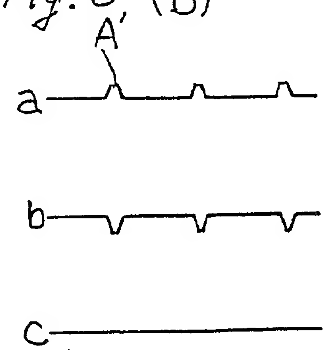
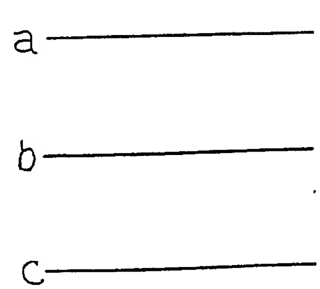
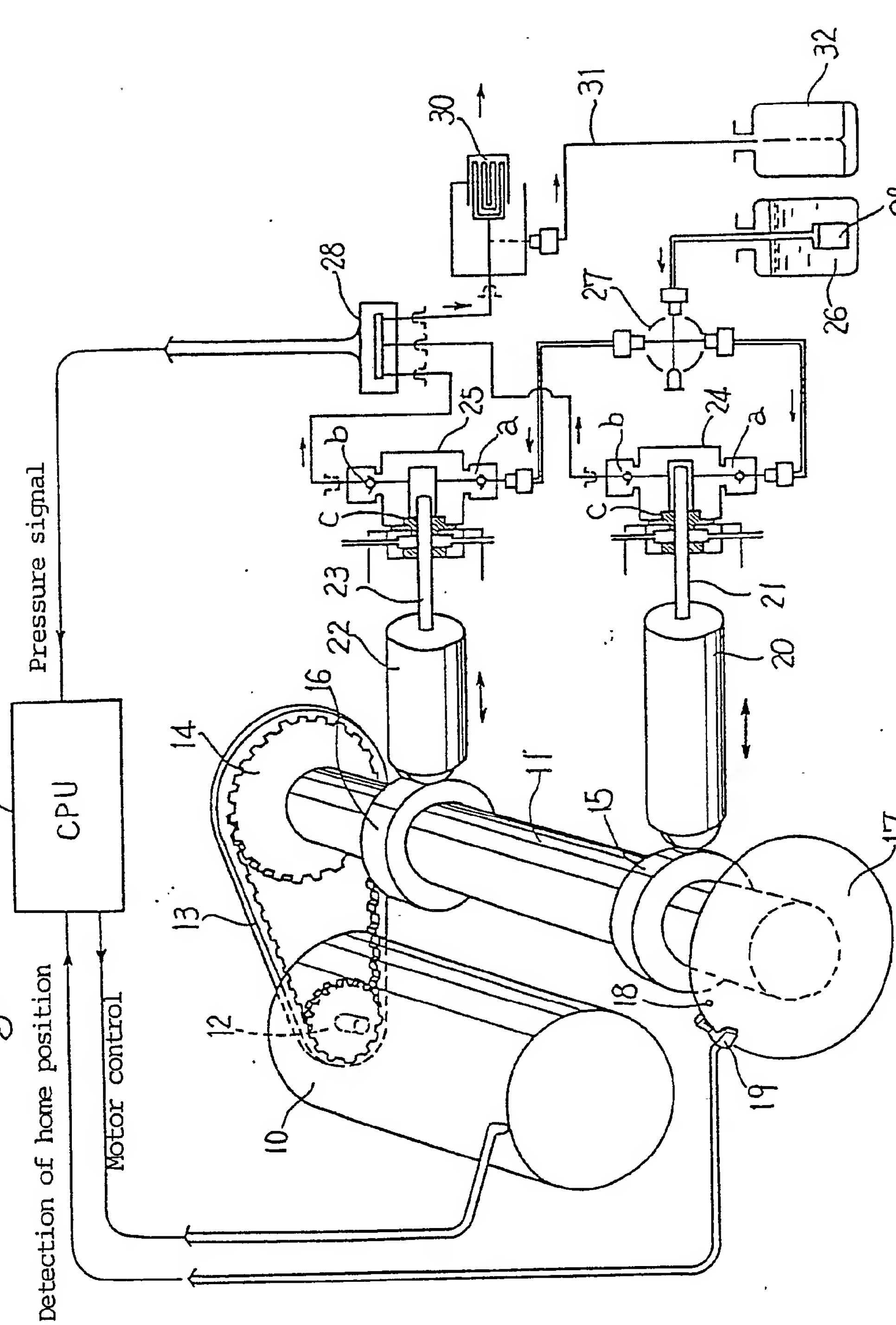


Fig. 3 (C)




CPU
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Pressure signal
Motor control
Detection of home position
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Fig. 2

Fig. 4

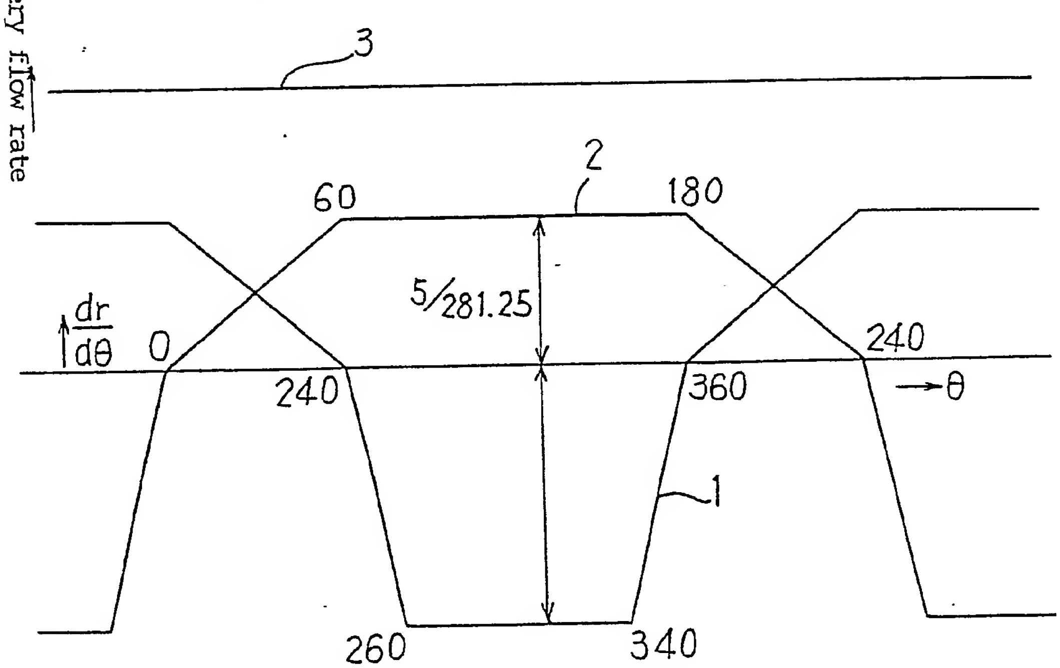


Fig. 5

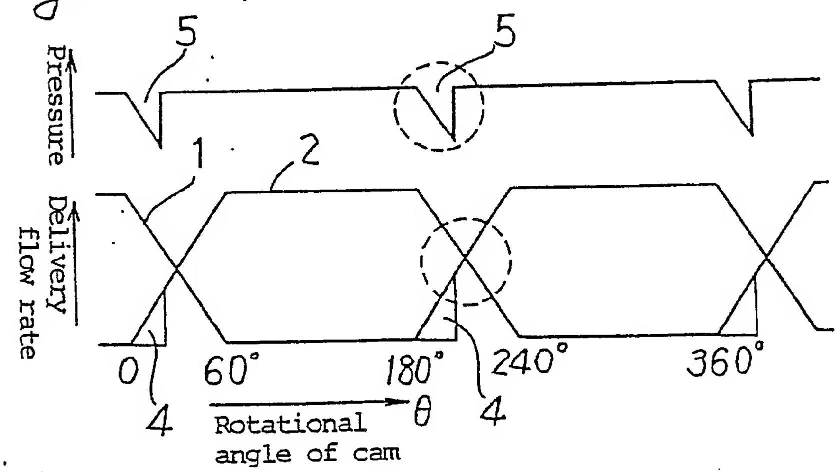


Fig. 6 (A)

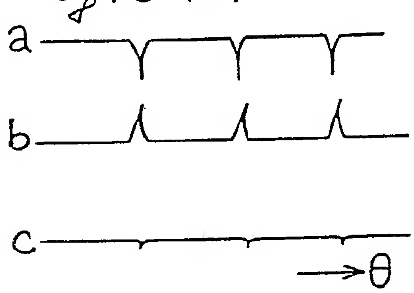
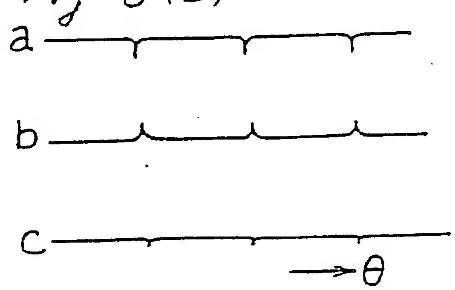


Fig. 6 (B)



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EUROPEAN SEARCH REPORT

Application Number

EP 88 11 6666

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	US-A-4 359 312 (FUNKE) * Column 4, line 55 - column 8, line 3; figures 1-10 *	1-3	F 04 B 11/00 F 04 B 49/00
X	US-A-4 352 636 (PATTERSON) * Column 5, line 21 - column 10, line 53; figures 1,2,11-16,18 *	1-3	
A	FR-A-2 580 833 (GIRA) * Page 4, line 12 - page 6, line 28; figures 1-4 *	1,2	
A	DE-A-2 446 805 (LEWA) * Page 4, paragraph 9 - page 6, paragraph 2; figures 1-4 *	1,2	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			F 04 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	08-06-1989	BERTRAND G.

CATEGORY OF CITED DOCUMENTS

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